Chapter 7
A Robust Sequence Synchronization Unit for Multi-user Chaos Based DS-CDMA Communication Systems

This chapter demonstrates two ways of achieving and maintaining sequence synchronization in multi-user chaos based direct sequence code division multiple access (CBDS-CDMA) communication systems. In both cases, synchronization is achieved and maintained through code acquisition and code tracking phases, respectively. The performance of the proposed systems is evaluated in the presence of additive white Gaussian noise and interuser interferences as well as in a Rayleigh fading channel. A pseudo random binary sequence (PRBS) and a logistic chaotic map are used as the synchronizing periodic, and non-periodic, pilot signals within the multi-user chaotic communication system. In addition, the Bernoulli chaotic map is also used as the pilot signal in the investigation of the code acquisition performance. The code acquisition circuit is evaluated in terms of the probability of detection and probability of false alarm. The corresponding results demonstrate an ability to achieve initial synchronization. Furthermore, it is shown that in terms of code acquisition the PRBS outperforms the logistic and Bernoulli chaotic maps when used as pilot signals. The mathematical models of the code tracking loops are then developed and their validity demonstrated by means of a simulation for both PRBS and chaotic pilot based CBDS-CDMA systems. From the models, the control laws for the generation of time offset estimates are derived. The robustness of the synchronization units is then demonstrated in terms of the bit error rate. It has been shown that for the PRBS based system, in an AWGN channel, for the case of 1, 2, 3, 4, and 5 users the bit error rate goes below the maximum acceptable limit of $10^{-3}$ at the bit energy to noise power spectral density ratio of approximately 8, 9, 9.5, 11 and 12 dB, respectively. The chaotic pilot based CBDS-CDMA systems exhibit marginally better performance for a single user plus a chaotic pilot signal than the corresponding PRBS pilot based CBDS-CDMA system at the BER level of $10^{-4}$ and below. In particular, at the BER level of $10^{-6}$, this improvement in performance is approximately equal to 0.175 dB. Their BER performances match for more than one user in the system. It has also been shown that the periodic and non-periodic chaotic pilot based CBDS-CDMA systems’ BER performances match for any number of users in the system. Furthermore a gradual degradation in performance, above the maximum acceptable
bit error rate limit, is demonstrated for the increasing number of users for all systems. Finally, it is shown that although the systems are robust to the influence of AWGN and interuser interferences, they all fail to satisfy the maximum allowable bit error rate limit of $10^{-3}$ in the Rayleigh fading channel. By introducing a chaotic pilot signal in place of a PRBS signal, the CBDS-CDMA system is made fully chaotic. In this way, the CBDS-CDMA systems’ security is significantly improved by eliminating an inherently different PRBS pilot signal.

As mentioned in chapter 3, the synchronization of chaotic systems was first studied by Yamada and Fujisaka in 1983 [1], and Afraimovich et al. in 1986 [2]. However it was not until 1990 when Pecora and Carroll (PC) introduced their method of chaotic synchronization (CS) [3] and suggested application to secure communications that the topic started to arouse major interest. The chaotic synchronization of [3] is most often established by employing Lyapunov’s direct method [4-6] or by considering the conditional Lyapunov exponents [7-9], leading to the design of the chaotic communication systems. Alternatively, the synchronization techniques of traditional spread spectrum communication systems [10-15] achieve synchronization between the transmitter and receiver in two distinct phases. These are called the code acquisition and the code tracking phase [10-21]. The code acquisition [11,10,13,14,15,18,20,21], or the initial synchronization phase, involves determining the time offset amidst the incoming signal and the basis function copy at the receiver to within a specified range known as the pull-in region of the tracking loop [11,12,10,15-17,19]. Upon the successful completion of the acquisition phase, the code tracking phase starts with the fine alignment followed by the process of maintaining synchronization of the two signals. Due to the mutually orthogonal properties of some chaotic signals [22-25] the synchronization techniques of the traditional code division multiple access (CDMA) spread spectrum communication systems have a potential to be applied to the chaotic communication systems [24,26-36]. In most cases, when evaluating the sequence synchronization of the chaos based DS-CDMA systems the code acquisition is analysed only [24,26,27,29-35]. In [26,27] Setti et. al. investigate the acquisition procedure of a chaos based DS-CDMA system and briefly discuss the possible general model for the tracking operation. The tracking model of [26,27] is essentially based on a continuance of the acquisition procedure and it does not deal with the synchronization within the chip level which is required for the fine alignment between the received and the despreading sequences. It has been suggested in [26,27] that the Bernoulli and the Tailed Shift chaotic maps may in fact yield somewhat better performance during the code acquisition phase than the classical spread spectrum sequences such as $m$ (PRBS) and Gold sequences. Furthermore, in [29], the authors use the Gaussian approximation for the self-interference term to show its effect on the acquisition performance. In [30] the moments approach is used to obtain a more accurate characterization of the self-interference term. Throughout [26,27,29,30] the noise has not been included in the system in order to study the effects of the interuser interferences on the acquisition performance. However in any real communication system noise is an inevitable part of operation and is thus included here in the study of the system performance. In [32,34] the authors look at the acquisition performance of Markov chaotic sequences...